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Modeling Yield Response of Groundnut to Deficit Irrigation at Different Growth Stages by FAO CROPWAT

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Deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on yield. Models can play a major role in developing practical recommendations for optimizing crop production under conditions of scarce water supply. To assess the applicability of the FAO CROPWAT model on deficit irrigation scheduling for groundnut, the study was undertaken using data from the field experiments conducted at Agricultural Research Station, Bhavanisagar, Tamil Nadu during summer 2005 and *Rabi* 2005-2006. Procedures were developed to calibrate the various crop parameters based on research findings from the experiment. Observed yield reduction and the predicted yield reduction revealed that the moisture stress imposed during flowering and pod formation stages were more sensitive than other stages. From the analysis, it is concluded that the CROPWAT model can effectively simulate yield reduction as a result of moisture stress imposed by deficit irrigation at various growth stages.

Key words: CROPWAT model, deficit irrigation, yield response factor.

Dwindling water resources and increasing food requirements require greater efficiency in water use in irrigated agriculture. In this context, deficit irrigation can play an important role in increasing water use efficiency. The objective of deficit irrigation is to save water by subjecting crops to periods of moisture stress with minimal effects on yields. The moisture stress results in less ET by closure of the stomata, reduced assimilation of carbon and decreased biomass production. The reduced biomass produ ction has little effect on ultimate yields when the crop is able to compensate in terms of reproductive capacity.

Models that simulate crop growth and water flow in the root zone can be a powerful tool to extrapolate findings and conclusions from field studies to conditions not tested, allowing predictions for deficit irrigation scheduling under various conditions of water supply and of soil and crop management.

The CROPWAT model developed by the FAO Land and Water Development Division (Smith, 1992) includes a simple water-balance model that allows the simulation of crop water stress conditions and estimations of yield reductions based on well established methodologies for determination of crop ET (Allen *et al.,* 2002) and yield responses to water (Doorenbos and Kassam, 1979).

To assess the applicability of the CROPWAT model for deficit irrigation scheduling for groundnut, a study was undertaken using data from the field experiments conducted at Agricultural Research Station, Bhavanisagar, Tamil Nadu during summer 2005 (April-August) and *Rabi* 2005-2006 (December-March).

Materials and Methods

Data from the field studies were used to evaluate the utility of the CROPWAT model in simulating deficit irrigation scheduling. In the field studies, various irrigation treatments were applied, inducing moisture stress at various crop growth stages, with soil moisture status determined over the growing season. The reported informations on climate, soil and crop were taken as input data while experimental yield and crop consumptive water use were used to validate the various crop parameters used in crop water model.

CROPWAT model

CROPWAT is a computer programme for irrigation planning and management, developed by the Land and Water Development Division of FAO (Smith, 1992). Its basic functions include the calculation of reference crop evapotranspiration, crop water requirements and irrigation schemes. Through a daily water balance, the user can estimate yield reductions, irrigation and rainfall efficiencies under various simulated water supply conditions. Typical applications of the water balance include the development of irrigation schedules for various crops and various irrigation methods, evaluation of irrigation practices, as well as rain-fed production and moisture stress effects. Calculations and outputs are based on the CROPWAT v. 4.0.

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Calculation of reference crop evapotranspiration is based on the FAO Penman-Monteith method (Allen *et al.,* 2002). Input data include maximum and minimum temperatures (°C), relative humidity (%), sun shine (hours) and wind speed (ms^{-1}). Crop evapotranspiration (ET_{crop}) over the growing season are determined from reference crop evapo transpiration (ETo) and estimate of crop evaporation rates, expressed as crop coefficients (k_c), based on well established procedures (Doorenbos and Pruitt, 1977), according to the following equation

$ET_{crop} = k_c * ET_o$ (under no moisture stress condition)

The effect of moisture stress on yield is quantified by relating the relative yield decrease to the relative evapotranspiration deficit through an empirically derived yield-response factor (K_y), according to methodology described by (Doorenbos and Kassam, 1979)

$$1 - \frac{Y_a}{Y_{max}} = K_y \left(1 - \frac{ET_a}{ET_{max}} \right)$$

where: $1 - \frac{Y_a}{Y_{max}}$ = the fractional yield reduction as a result of the decrease in evaporation rate.

rate $\left(1 - \frac{ET_a}{ET_{max}} \right)$

Table 1. Treatment details

Treatment	Irrigation method	Allowable depletion factor*			
		Vegetative stage	*Flowering stage*	*Pod formation stage*	*Maturity stage*
$T_{control}$	Conventional surface irrigation	0.50-0.60	0.50-0.60	0.50-0.60	0.50-0.60
T_{1111}	Micro sprinkler irrigation	0.50-0.60	0.50-0.60	0.50-0.60	0.50-0.60
T_{0111}		0.75-0.80	0.50-0.60	0.50-0.60	0.50-0.60
T_{1011}		0.50-0.60	0.75-0.80	0.50-0.60	0.50-0.60
T_{1101}		0.50-0.60	0.50-0.60	0.75-0.80	0.50-0.60
T_{1110}		0.50-0.60	0.50-0.60	0.50-0.60	0.75-0.80
T_{0000}		0.75-0.80	0.75-0.80	0.75-0.80	0.75-0.80

*Allowable depletion factor of 0.50 to 0.60 corresponds to full irrigation and that of 0.75 to 0.80 corresponds to deficit irrigation.

T_{1111} - normal irrigation through micro sprinklers at all stages

T_{0111} - deficit irrigation at vegetative stage through micro sprinklers

T_{1011} - deficit irrigation at flowering stage through micro sprinklers

T_{1101} - deficit irrigation at pod formation stage through micro sprinklers

T_{1110} - deficit irrigation at maturity stage through micro sprinklers

T_{0000} - deficit irrigation at all four stages through micro sprinklers

Field experiments

In this study, an optimum irrigation scheduling for groundnut under deficit irrigation, was carried out. Seven irrigation treatments with combinations of method of irrigation and different levels of moisture stress at different stages of crop growth as given in Table 1.

Table 2. Comparison of CROPWAT predicted and observed values

Particulars	Summer 2005				
	Growth stage				
	Vegetative	Flowering	Pod formation	Maturity	Total
Length (days)	**25**	**25**	**25**	**33**	**108**
	Crop coefficient (K_c)				
CROPWAT calibration	0.40	0.70	0.90	0.50	
CROPWAT standard (Allen *et al.,* 2002)	0.40	→[a]	1.05	0.60	
Calculated K_c	0.44	0.65	1.17	0.65	
Crop height (m)	0.15	0.27	0.40	0.45	
Rooting depth (m)	0.10	0.17	0.25	0.50	
Depletion factor (fraction)	0.45	0.45	0.45	0.50	
	Yield response factor (k_y)				
CROPWAT calibration	0.20	0.85	0.75	0.30	0.75
Calculated from experiment	0.23	0.87	0.83	0.35	0.85
Doorenbos and Kassam (1979)	0.20	0.80	0.60	0.20	0.70

Table 2 Cont.

Particulars	*Rabi* 2005-2006				
	Growth stage				
	Vegetative	Flowering	Pod formation	Maturity	Total
Length (days)	**25**	**25**	**25**	**35**	**110**
	Crop coefficient (K_c)				
CROPWAT calibration	0.40	0.75	0.95	0.55	
CROPWAT standard (Allen *et al.,* 2002)	0.40	→[a]	1.05	0.60	
Calculated K_c	0.47	0.70	1.21	0.67	
Crop height (m)	0.17	0.29	0.40	0.46	
Rooting depth (m)	0.10	0.18	0.25	0.50	
Depletion factor (fraction)	0.45	0.45	0.45	0.50	
	Yield response factor (k_y)				
CROPWAT calibration	0.20	0.80	0.70	0.30	0.72
Calculated from experiment	0.21	0.85	0.80	0.32	0.75
Doorenbos and Kassam (1979)	0.20	0.80	0.60	0.20	0.70

[a] intermediate value

Analysis

The analysis were conducted by using the climatic, crop and soil data and the conditions as given in the field experiments. The standard crop data given in the CROPWAT model were calibrated using a step-wise procedure. In the first step, the k_c values and the critical depletion factor were adjusted such that they met conditions and data for the optimal irrigation treatment, under no moisture stress condition. In subsequent steps, the treatments were analyzed and the yield response factor (K_y) adjusted to achieve the experimental yield responses to moisture imposed during the various crop growth stages.Optimal irrigation *i.e.,* no moisture stress, was applied by allowing depletion to 60 per cent of total available soil moisture.

Results and Discussion

Calibrations of CROPWAT crop parameters for groundnut adjusted for the optimum irrigation schedule are presented in Table 2. K_c values were well below expected standard values for groundnut (Allen *et al.,* 2002). Rooting depth and depletion factor (level) corresponded to standard values expected for groundnut. Yield response factors corresponded well with those reported by Doorenbos and Kassam (1979).

Observed and predicted (CROPWAT) yield reductions for each treatment are presented in Table 3. It is expressed as a percentage of the yields of (Y_{max}) 2097 and 2127 kg ha^{-1} for summer 2005 and *Rabi* 2005-2006, respectively.

Observed yield reductions revealed that flowering and pod formation stages are highly sensitive to moisture stress. Observed yield reductions seem somewhat less consistent with larger deviations from CROPWAT's calculated values, which needs an upward adjustment of the yield response factor that may be required for the total growing season (Smith *et al.,* 2000).

The use of the CROPWAT model can provide useful insights into the design of irrigation studies and parameters selected for irrigation treatments.

Table 3. Comparison of observed and CROPWAT predicted yield reductions for groundnut

Treatment	Summer 2005			*Rabi* 2005-2006		
	Observed		CROPWAT	Observed		CROPWAT
	Yield (kg ha^{-1})	Yield reduction (per cent)	Yield reduction (per cent)	Yield (kg ha^{-1})	Yield reduction (per cent)	Yield reduction (per cent)
Surface irrigation (control)	2097*	0	0	2127*	0	0
Normal water in all four stages	2010	4.1	3.4	2037	4.2	3.7
Stress at all four stages	900	57.1	55.3	987	53.6	51.4
Stress at vegetative stage	1913	8.8	7.6	1970	7.4	7.1
Stress at flowering stage	1610	23.2	21.4	1688	20.6	18.7
Stress at pod formation stage	1565	25.4	23.8	1644	22.7	19.9
Stress at maturity stage	1696	19.1	17.7	1809	15.0	13.6

* Y_{max}

A more important application of simulation models is the possibility to extrapolate from the conditions of a study to more general field experiment and to explore the effects of irrigation scheduling under various levels of water supply. The CROPWAT model thus can be used to simulate yield response of groundnut under deficit irrigation using the calibrated crop data.

Conclusion

Based on this comparative analysis, it is concluded that the CROPWAT model can adequately simulate yield reduction to moisture stress imposed by deficit irrigation. It accounted well for the relative sensitivity of different growth stages and was able to reproduce the negative impact of moisture stress on yield.

Standard values provided by CROPWAT need to be adjusted to predict yield reductions as a result of moisture stress imposed by deficit irrigation. A step-wise procedure, developed to calibrate and adjust the crop parameters, resulted in predicting yield response of groundnut grown under deficit irrigation.

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